Coupling between the hydrographic circulation in the Strait of Sicily and the reproductive strategy of the European anchovy *Engraulis encrasicolus*: effects on distribution of spawning grounds

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Abstract

Some aspects of the effects of the hydrographic circulation on the reproductive strategy of the European anchovy (*Engraulis encrasicolus*, L. 1758) population off the southern coast of Sicily are illustrated, using information from satellite SST data and the horizontal distribution of anchovy eggs. Ichthyoplanktonic data used in this study were collected during six summer oceanographic surveys between 1997 and 2002. The general circulation pattern is locally controlled by the motion of the Modified Atlantic Water, the Atlantic–Ionian Stream (AIS). During summer, the water mass advected by the AIS to the south of Sicily is fresher and warmer than the water north of it at the same depth. This characteristic allows the use of temperature as a tracer of the AIS trajectory. The year-to-year variation in the AIS path, inferred from SST data, while confirming the existence of different environmental conditions along the southern coast of Sicily, appeared to be able to affect the anchovy spawning strategy. In fact, the analysis of available information allowed the identification of a correlation between the AIS trajectory and the location of major spawning grounds.

1. Introduction

The main hydrographic feature off the southern Sicilian coast is the Atlantic–Ionian Stream (AIS), a meandering surface current flowing towards the Ionian Sea. Its path and its year-to-year variation have consequences for the predominant hydrographical phenomena in the region, such as the extension of upwelling and the formation of frontal structures. All these hydrographical features have shown their influence on the spawning strategy of the European anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), and the survival of the early-life stages (García Lafuente *et al.*, 2002).

The AIS acts as a transport mechanism for displacing anchovy eggs and larvae from the more important northern spawning grounds towards the southern part of the region (García Lafuente *et al.*, 2002). During summer, the Atlantic water advected by the AIS to the south of Sicily is warmer than the water north of it at the same depth, a fact that is the consequence of the presence of the Adventure Bank Vortex (ABV; Robinson *et al.*, 1991, 1999; Warn-Varnas *et al.*, 1999) and the frequent wind-induced upwelling along the southern shore of the island (Piccioni *et al.*, 1988). The relationship between the meanders of the AIS and the surface thermal structures in the Strait has been stressed in oceanographic papers dealing with this area (Robinson *et al.*, 1999; Lermusiaux, 1999).

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If the AIS path is far offshore, the central-northern coast may have a greater extent of upwelling, thereby producing drastic changes in the temperature regime of the surface water. As a result, the anchovy, which prefers warm water, may refrain from spawning during the peak spawning season (summer). The contrary would occur if the AIS were closer to the coast: the ABV would be reduced in size and water in the coastal zone would increase in temperature because of the AIS's influence.

In this study, the effect of the general surface circulation on the anchovy spawning in the northern part of the Strait of Sicily was investigated. To this end, we analysed data collected in ichthyoplanktonic surveys from 1997 to 2002, during the peak of the anchovy spawning period (Giráldez and Abad, 1995; Cuttitta *et al.*, 1999).

2. Materials and methods

Six annual summer surveys were carried out from 1997 to 2002, aboard the R.V. "Urania", except in 1997 when the F.V. "S. Anna" was used, and in 1999 when the R.V. "Copernaut Franca" was used. Table 1 summarizes information on the surveys used in this study.

Table 1. List of surveys used in this study and related information.

Survey	**Vessel**	**Period**	**Number of stations**
ANSIC97	S. Anna	19 July–2 August 1997	85
BANSIC98	Urania	25 June–11 July 1998	127
BANSIC99B	Copernaut Franca	19–25 June 1999	70
BANSIC2000	Urania	24 June–8 July 2000	131
ANSIC2001	Urania	7–25 July 2001	144
ANSIC2002	Urania	11–31 July 2002	219

Figure 1 shows the map of the study area and the distribution of the plankton stations sampled during the survey series. A total of 776 stations were carried out: 85 in 1997; 127 in 1998; 70 in 1999; 131 in 2000; 144 in 2001; and 219 in 2002 (see Table 1). Sampling stations were based on a step-grid of 4–6 nautical miles on the continental shelf of the southern Sicilian coast, and on a 12-nautical-mile step-grid offshore. Oblique plankton hauls were carried out at a speed of 2 knots targeting at least 100 m depth, where possible, using a Bongo net system with a 40-cm mouth diameter and a mesh size of 0.2 mm for both sides of the frame.

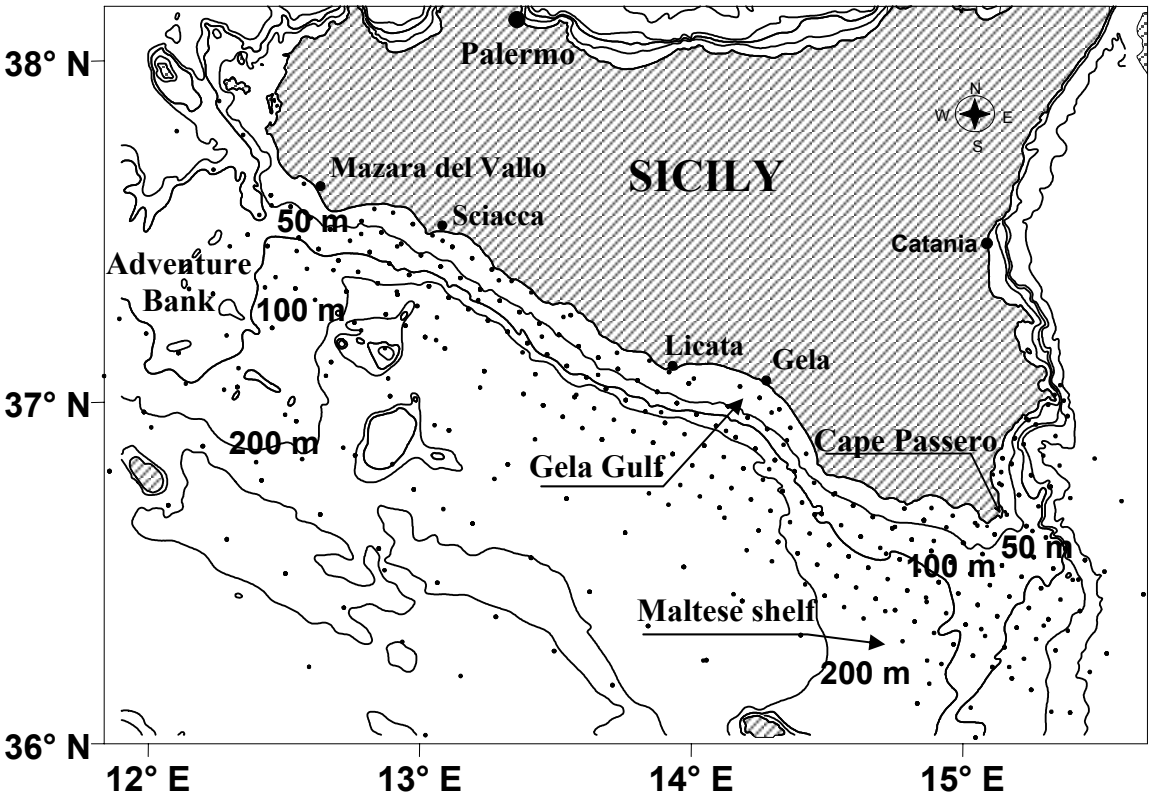

Figure 1. Map of study area including positions (•) of the Bongo-40 hauls and CTD cast stations; surveys 1997–2002.

Samples were preserved in 4% buffered formaldehyde and seawater solution. The sorting of ichthyoplankton samples was performed in the laboratory using a stereobinocular microscope at a magnification of 12×. Anchovy eggs were extracted and counted. Counts were interpolated (kriging method) for drawing purposes by means of Surfer Golden software.

Hydrographical data were acquired during the same cruises by means of CTD probe model SBE 911. CTD casts were analysed using Ocean Data View software, and the path of AIS was initially depicted by the minimum-salinity isohaline.

Temperature and salinity fields in the Strait of Sicily are controlled by the AIS dynamics to a great extent. As a general rule, temperature and salinity are correlated in the sense that the warmer the water, the fresher it is. This is the expected result if the warm water is advected by the AIS, whose main hydrographical characteristic is a salinity minimum. Because of the specific relationship between temperature and salinity that is observed in this area, temperature can serve as a tracer of the AIS trajectory off the southern coast of Sicily. Specifically, the analysis of CTD data suggested that any isotherm whose numerical value were close to 22ºC or 24ºC (depending on whether the SST image was for June or for July) would be indicative of the AIS path in the Strait in June–July, the time of the year when the surveys were carried out (Mazzola *et al.*, 2002).

In this study, in order to infer the AIS trajectory, SST satellite images derived from NOAA/AVHRR (infrared sensor) data were analysed. The spatial resolution of these images, a value-added product of the German Remote Sensing Data Centre (DLR), is 1.1 km. Composite images for the survey periods were produced by averaging the temperature of the corresponding daily images at each pixel.

3. Results

The development from egg to larval stage is temperature-dependent and for anchovy in this area takes 24–36 h (Holden and Raitt, 1975). So, the presence of eggs indicates the location of spawning grounds. Specifically, the analysis of anchovy-egg distribution allowed the identification of three main spawning areas off the southern coast of Sicily (see Figure. 2 a–f): (1) Northern, over the Adventure Bank; (2) Central, in coastal areas from Sciacca to Licata; and (3) Southern, over Gela Gulf and the Maltese shelf. However, the relative importance of these spawning areas underwent wide variations between 1997 and 2002.

Table 2 represents an attempt, based on the presence and abundance of anchovy eggs during the surveys analysed in this study, to qualitatively depict the spawning activity in the known spawning areas. In 1997 and 1998, the most important spawning grounds were the central and southern ones; in 1999, only the southern area appeared to be actively occupied; in 2000 and 2001, anchovy eggs were most abundant in both the northern and southern grounds, but not in the central one; in 2002 very low anchovy-egg densities were detected in all spawning grounds.

Table 2. Spawning activity in the main spawning areas detected off the southern coast of Sicily. "o" = absence of eggs; "+", "++" = presence of eggs above or well above the average, respectively; "–", "—" = presence of eggs below or well below the average, respectively.

Survey	**Spawning areas**		
	Northern	Central	Southern
ANSIC97	o	+	+
BANSIC98	–	++	++
BANSIC99B	o	–	+
BANSIC2000	+	–	+
ANSIC2001	++	–	++
ANSIC2002	o	—	—

Observed egg distributions are consistent with the SST maps in Figure 3 a–f. Specifically, the warm AIS water was advected over the central and southern spawning areas in 1997 and 1998, and mainly over southern spawning ground in 1999, 2000 and 2001, though in the last two years even the northern area gained in importance. In 2002, the AIS path was quite far offshore, producing a great general decrease in sea-surface temperature off the southern coast of Sicily.

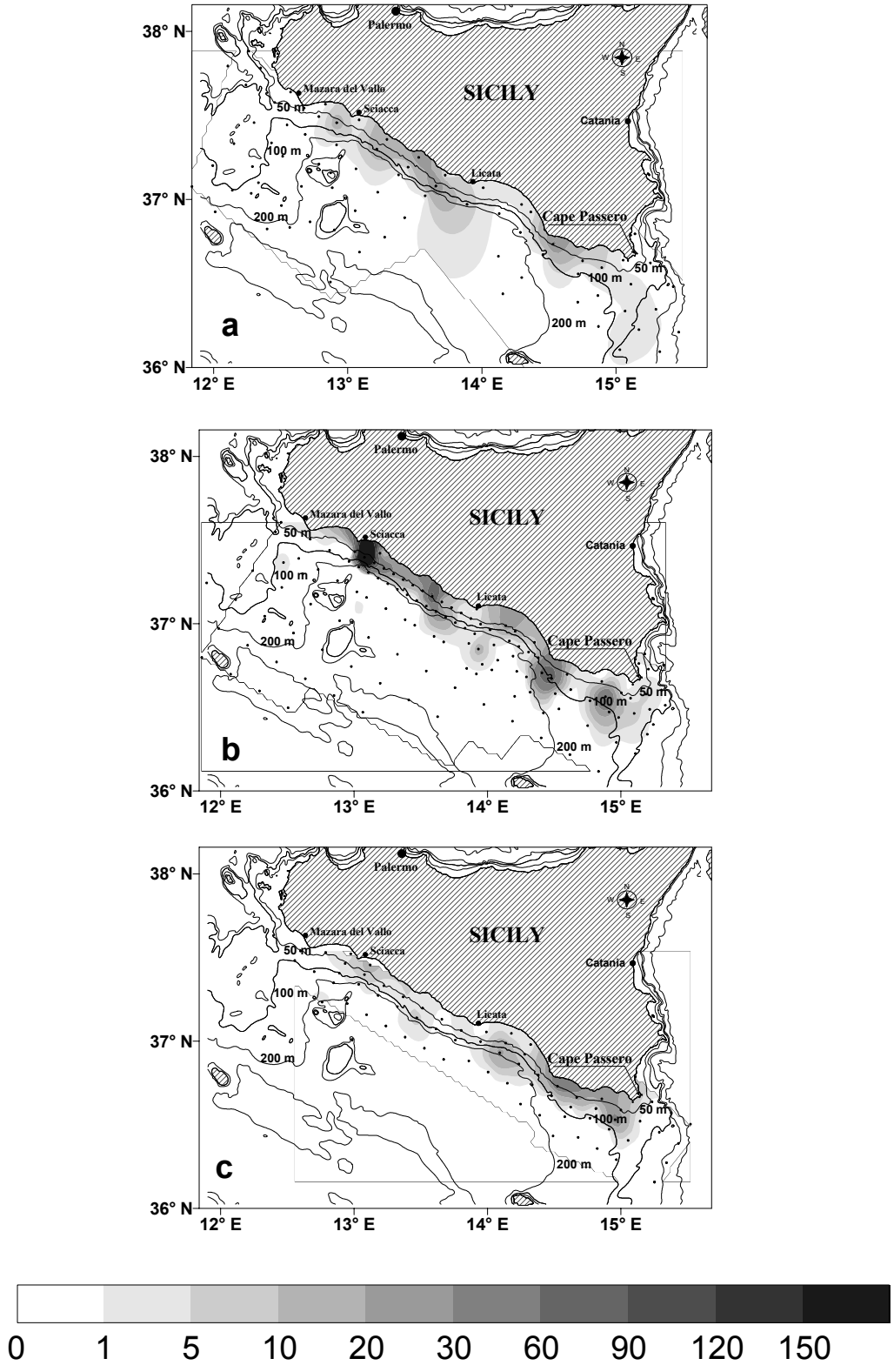

Figure 2. Distribution of anchovy eggs (counts per haul) during surveys carried out along the Sicilian coast in 1997 (**a**), 1998 (**b**), 1999 (**c**), 2000 (**d**), 2001 (**e**) and 2002 (**f**).
(continued)

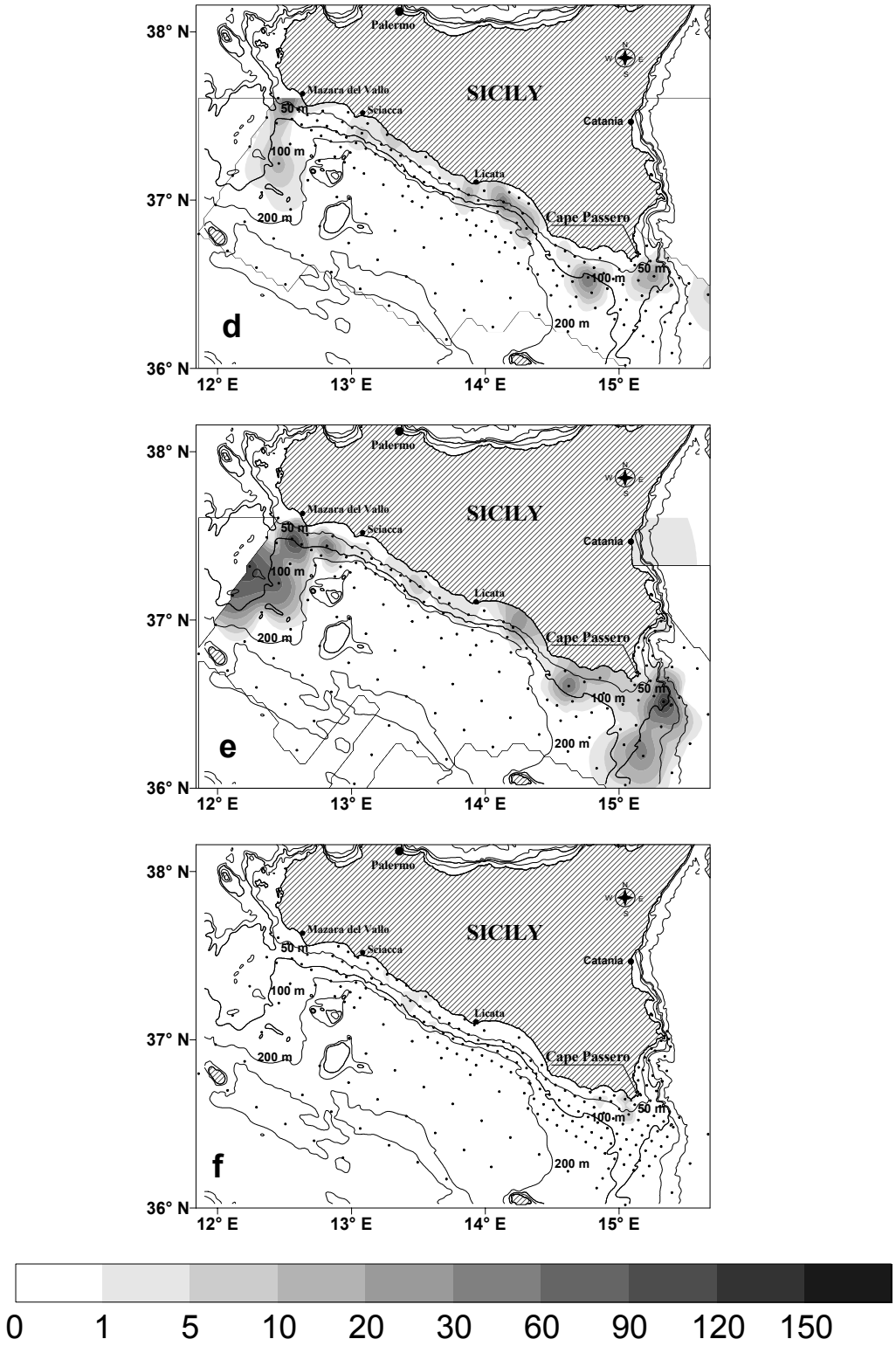

Figure 2 (continued).

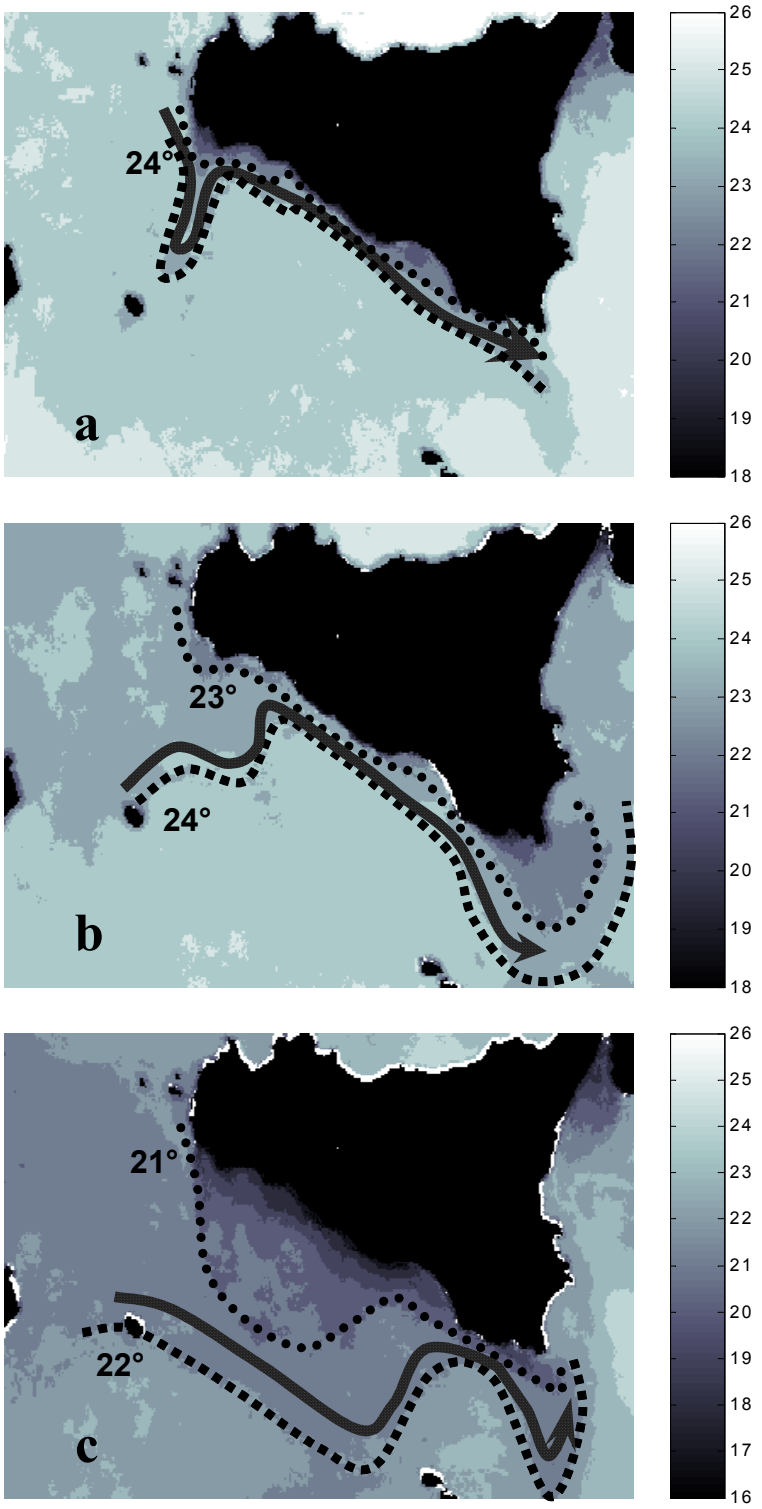

Figure 3. Composite images of daily sea-surface temperature during the surveys ANSIC97 (**a**), BANSIC98 (**b**), BANSIC99B (**c**), BANSIC00 (**d**), ANSIC01 (**e**) and ANSIC02 (**f**). The 23ºC and 24ºC isotherms (for 1999: 21°C and 22°C) have been labelled. The meandering arrows are tentative representations of the AIS, taking those two isotherms as being indicative of its trajectory. (continued)

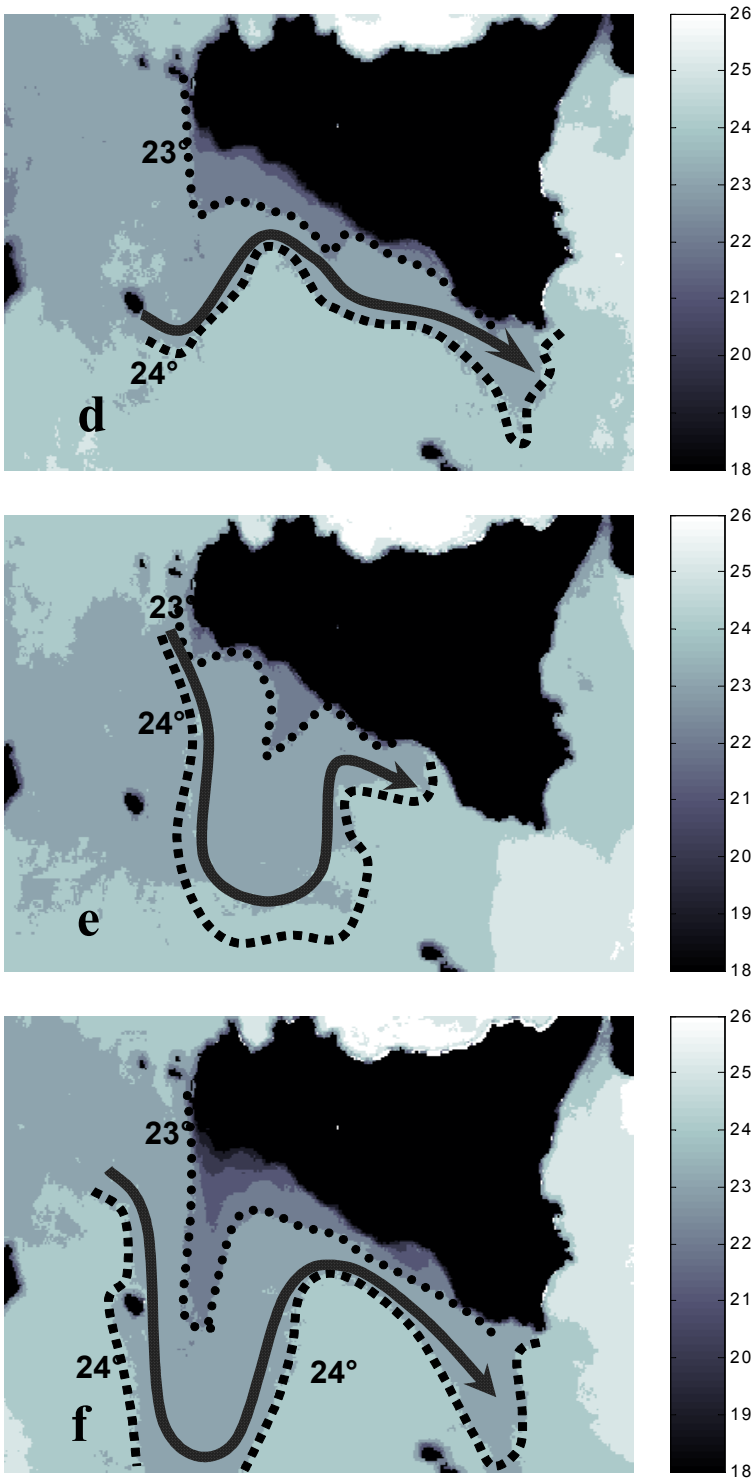

Figure 3 (continued).

4. Discussion and conclusion

The analysis of ichthyoplanktonic samples allowed the identification of a correlation between the horizontal distribution of anchovy eggs and the AIS trajectory; the latter is quite variable from one year to the next, may produce changes in the temperature range and in the extent of the upwelling in the northern part of the area. This in turn may reflect upon the distribution of

the anchovy spawning grounds, since a low-temperature regime may inhibit spawning. The preference of the anchovy in the Strait of Sicily for spawning in warmer water, proposed by Mazzola *et al.* (2002) and García Lafuente *et al.* (2002), were confirmed by the results of the present study, showing that surface thermal features due to the AIS, in terms of its distance from the coast, may be successfully used as an indicator of anchovy spawning.

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